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ORIGINAL ARTICLE

Temporal water quality response in an urban river: a case study in peninsular Malaysia

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Abstract Ambient water quality is a prerequisite for the health and self-purification capacity of riverine ecosystems. To understand the general water quality situation, the time series data of selected water quality parameters were analyzed in an urban river in Peninsular Malaysia. In this regard, the stations were selected from the main stem of the river as well as from the side channel. The stations located at the main stem of the river are less polluted than that in the side channel. Water Quality Index scores indicated that the side channel station is the most polluted, breaching the Class IV water quality criteria threshold during the monitoring period, followed by stations at the river mouth and the main channel. The effect of immediate anthropogenic waste input is also evident at the side channel station. The Organic Pollution Index of side channel station is (14.99) ~3 times higher than at stations at river mouth (4.11) and ~6 times higher than at the main channel (2.57). The two-way ANOVA showed significant difference among different stations. Further, the factor analysis on water quality parameters yielded two significant factors. They discriminated the stations into two groups. The land-use land cover classification of the study area shows that the region near the sampling sites is dominated by urban settlements (33.23 %) and this can contribute significantly to the deterioration of ambient river water quality. The present study estimated the water quality condition and response in the river and the study can be an immediate yardstick for base lining river water quality, and a basis for future water quality modeling studies in the region.

Keywords Dissolved oxygen · Biochemical oxygen demand · Organic pollution index · Urban river · Peninsular Malaysia

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Introduction

Rivers are lifelines for human societies around the globe, embodying immense influence in shaping civilizations. The catchment area usually supports a wide variety of flora and fauna, creating a very diverse ecosystem composed of ecologically delicate and inter related, physical, chemical and biological entities. However, rivers are also the subsequent waste disposal arena for anthropogenic activities and are pathways of waste materials to coastal regions. Although the global water crisis tends to be viewed as a water quantity problem, water quality is increasingly being acknowledged as a central factor in the water crisis (Belayneh and Bhallamudi 2012). The quality of river water is a deterministic factor for the healthy, sustainable survival of the riverine ecosystem, which primarily depends on the Waste Assimilative Capacity (WAC) of the water. WAC is the natural ability of the river to withstand or assimilate a certain amount of pollutants without impairing ambient water quality

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conditions (Krom 1986; Tett et al. 2011). Increasing anthropogenic contaminants affect WAC and water quality is deteriorated beyond WAC of a water body (VishnuRadhan et al. 2014, 2015). This can disrupt the prevailing ecological homeostasis, ultimately affecting the riverine health.

In water quality management, the determination of each water quality variable is important to obtain collective information on water quality, as it can provide concise information on overall environmental conditions (Chen et al. 2007). Practically, it is difficult to assess water quality based on each parameter/variable. The water quality indices of significant and influential parameters aim at giving a single value to the water quality of a source on the basis of a system which translates their existing concentrations in a sample into a single value. These values are used as communication tools by regulatory agencies to describe the quality or health of a specific environmental system (Abbasi and Abbasi 2012). The WQI is frequently utilized as a mathematical tool for evaluating water quality status around the globe (Shirodkar et al. 2010; Lumb et al. 2011; Gazzaz et al. 2012; Dede et al. 2013).

In urban areas, streams are often degraded as they are diverted through storm water runoff systems, removal of riparian vegetation, and the construction of roads, parking lots and buildings (Buffers 2000). Riparian zones have diversified functions that include preserving bank stability, functioning as habitats for streamside living organisms and also playing a critical role in preserving the water quality of rivers by filtering out pollutants from runoff (Zainudin et al. 2013). Water quality is a major factor impacted by anthropogenic action at landscape scales which is a principal threat to the ecological integrity of river ecosystems (Allan 2004). Land-use changes often affect the water quality over a long historical period (Garnier et al. 2013) and future land-use changes will exacerbate the water quality problems (Whitehead et al. 2013). The changes in ecosystem goods and services that result from land-use change revert on the drivers of land-use change (Lambin et al. 2003). Many studies have quantified the effect of population increase on land use/land cover (LULC) (Meyers and Turner 1992; Wu et al. 2013; Meyfroidt et al. 2013) and the associated anthropogenic activities can ultimately reflect on the water quality of natural waters. Thus, LULC can give a generalized impression on the state of a river's water quality in an urban area.

To understand the water quality situation and contribution of anthropogenic activities on the water quality degradation in an urban river, an investigation was performed using time series data on water quality parameters. In this regard, a suite of selected referred water quality indices, GIS and statistical techniques were attempted in the present study. The present study is first of its kind in Sg. Sri Melaka and will contribute to the baseline information for future water quality studies in the region.

Materials and methods

Study area

Sg. Sri Melaka/Sg. Malim is a small urban river, located in the state of Melaka in southern Peninsular Malaysia. The climate of the region is generally characterized as humid tropical and peak rainfall commences in September and ends abruptly around November. In March, the rainfall amount rises again and a smaller peak occurs in April. The rainfall amount remains virtually constant until September (Asry et al. 2012). The river, which drains into the Straits of Malacca (Fig. 1a), is frequently used for recreational fishing. Near the river mouth, the waste water discharge is more domestic than industrial. Floodgates located on the channel trap pollutants from being flushed out to sea, as they are closed most of the time. This results in a grotesque condition on this particular stretch. Debris and floatables are observable, indicative of its polluted physico-chemical state. Moreover, there is an urban settlement that may be exposed to foul odor emanating from the channel due to anoxic biodegradation. Land reclamation works are also currently going on downstream (mouth region), paving the way for future development. The locations of the sampling stations are shown in Fig. 1b, whereas Table 1 describes each sampling station and its relevance to the study. Three stations were selected for the present study: one at the side channel, the second at the main stem of the river and the third one at the river mouth.

Water quality data

Time series data of water quality parameters from the three sampling stations were collected from the basin. In this regard, samples were collected at 3-h intervals for 3 days from 23rd to 26th of August 2010. The water quality parameters measured are pH, temperature, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), oil & grease, Phosphorous (P), Ammoniacal nitrogen (NH_3-N), and *E. coli*. The methodologies adopted for the sample analysis are presented in Table 2.

Water Quality Index

The primary method employed to classify the river water quality was the Water Quality Index (WQI) and the National Water Quality Standards (NWQS), a set of standards derived based on beneficial uses of water in Malaysia. The NWQS defined classes I–V, referred to classification of rivers or river segments based on the descending order of water quality: Class I being the best and Class V being the worst (Zainudin 2010). A WQI

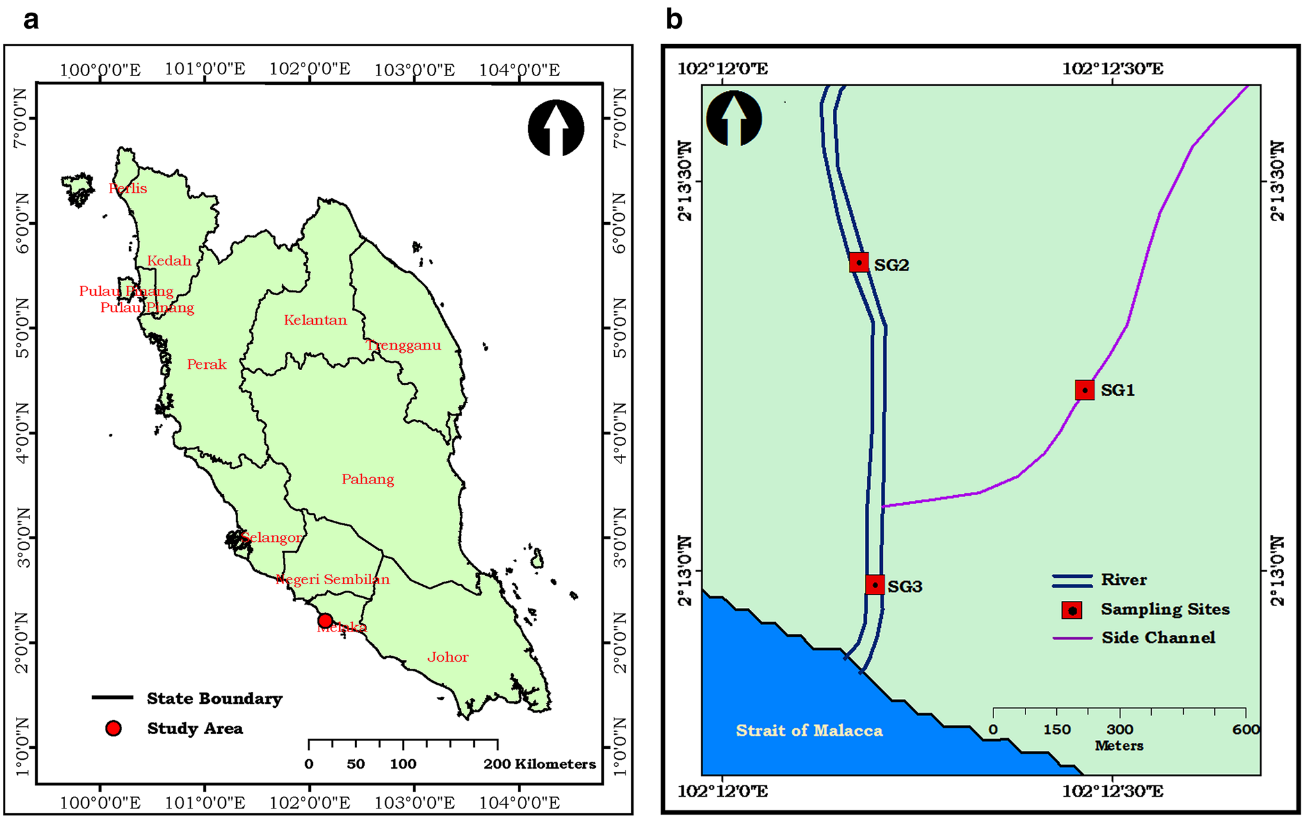

Fig. 1 **a** Study area (*red mark*); **b** station locations in the study area

Table 1 Description of the study area

Station	Coordinates	Description	Mean depth (m)	Mean width (m)
SG1	2°13.262′N, 102° 12.487′E	Ambient water sampling station, located on side channel itself and adjacent to residential area. Stagnant water conditions	0.62	7.51
SG2	2°13.333′N, 102° 12.185′E	Ambient water sampling station, located on the main stem of Sg. Malim/Sg. Sri Melaka	2.08	27.42
SG3	2°13.007′N, 102° 12.186′E	Ambient water sampling station, near to the river mouth	2.48	33.50

ascribes quality value to an aggregate set of measured parameters. It usually consists of sub-index values assigned to each pre-identified parameter by comparing its measurement with a parameter-specific rating curve, optionally weighted, and combined into the final index. The purpose of a WQI is to summarize large amounts of water quality data for a specific river into simple values (i.e., one number and a statement such as "good") (Saffran et al. 2001).

The WQI primarily used in Malaysia, also referred to as the Malaysian Department of Environment-Water Quality Index (DOE-WQI), is an opinion-poll formula where a panel of experts is consulted on the choice of parameters and on the weightage to each parameter (DOE 1985). The WQI is calculated using six parameters WQI: DO, BOD, COD, TSS, NH_3-N and pH with the inclusion of intermediate sub-indices. Calculations are performed on the water quality parameters to find out their respective sub-indices. The sub-indices are named SIDO, SIBOD, SICOD, SIAN, SISS and SIPH. The best fit equations used for the estimation of the six sub-indices are shown below (DOE 2007).

(a) Sub-index for DO (in % saturation): SIDO

$$\begin{aligned} \mathrm{SIDO} &= 0 && \text{for} \quad x \le 8\,\% \\ &= 100 && \text{for} \quad x \ge 92\,\% \\ &= -0.395 + 0.030x^2 - 0.00020x^3 && \text{for} \quad 8\,\% < x < 92\,\% \end{aligned}$$

(b) Sub-index for BOD: SIBOD

$$\begin{aligned} \mathrm{SIBOD} &= 100.4 - 4.23x && \text{for } x \le 5 \\ &= 108e^{-0.055x} - 0.1 && \text{for } x > 5 \end{aligned}$$

Table 2 Methodologies adapted for the sample analysis

No	Parameter	Unit	Analysis method
	pH @ 25 °C	–	APHA 4500-H-B
	Temperature	°C	APHA 2550
	Biochemical oxygen demand @ 20 °C, 5 days	mg/L	APHA 5210 B
	Chemical oxygen Demand	mg/L	APHA 5220 B
	Total suspended solids	mg/L	APHA 2540 D
	Dissolved oxygen	mg/L	APHA 4500 O G
	Oil and grease	mg/L	APHA 5520 B D
	Phosphorus	mg/L	APHA 4500 P B, C
	Ammoniacal nitrogen	mg/L	APHA 4500 NH_3 B
	E. coli	CFU/ 100 mL	In House Method LTM 7.1 Based on APHA 9222 B, 20th edition

(c) Sub-index for COD: SICOD

$$\begin{aligned} \mathrm{SICOD} &= -1.33x + 99.1 \quad \text{for } x \le 20 \\ &= 103e^{-0.0157x} - 0.04x \quad \text{for } x > 20 \end{aligned}$$

(d) Sub-index for NH_3-N: SIAN

$$\begin{aligned} \mathrm{SIAN} &= 100.5 - 105x \quad \text{for } x \le 0.3 \\ &= 94^{-0.573x} - 5|x-2| \quad \text{for } 0.3 < x < 4 \end{aligned}$$

(e) Sub-index for TSS: SISS

$$\begin{aligned} \mathrm{SISS} &= 97.5e^{-0.00676x} = 0.05x \quad \text{for } x \le 100 \\ &= 71e^{-0.0016x} - 0.015x \quad \text{for } 100 < x < 1000 \\ &= 0 \quad \text{for } x \ge 1000 \end{aligned}$$

(f) Sub-index for pH: SIPH

$$\begin{aligned} \mathrm{SIPH} &= 17.2 - 17.2x + 5.02x^2 \quad \text{for } x < 5.5 \\ &= -242 + 95.5x - 6.67x^2 \quad \text{for } 5.5 \le x < 7 \\ &= -181 + 82.4x - 6.05x^2 \quad \text{for } 7 \le x < 8.75 \\ &= 536 - 77.0x + 2.76x^2 \quad \text{for } x \ge 8.75 \end{aligned}$$

Table 4 DOE water quality classification based on water quality index

Parameters	Index range		
	Clean	Slightly polluted	Polluted
SIBOD	91–100	80–90	0–79
SIAN	92–100	71–91	0–70
SISS	76–100	70–75	0–69
WQI	81–100	60–80	0–59

where x is the concentration in mg/L for all parameters except pH.

Once the respective sub-indices have been calculated, the WQI can then be calculated using Eq. (1).

$$\begin{aligned} \mathrm{DOE-WQI} = {} & 0.22 * \mathrm{SIDO} + 0.19 * \mathrm{SIBOD} + 0.16 \\ & * \mathrm{SICOD} + 0.15 * \mathrm{SIAN} + 0.16 * \mathrm{SISS} \\ & + 0.12 * \mathrm{SIPH} \end{aligned} \tag{1}$$

The summation of the weightages for all the sub-indices must have a value of unity. The respective class designation for the WQI scores is shown in Tables 3 and 4.

Organic pollution index

Organic Pollution Index (Wei et al. 2009) is an immediate and reliable measure of river water quality and pollution. The equation is as follows:

$$A = \frac{BOD_i}{BOD_0} + \frac{COD_i}{COD_0} + \frac{NH_3 - N_i}{NH_3 - N_0} - \frac{DO_i}{DO_0} \tag{2}$$

where A is the OPI, while BOD_i, COD_i, NH_3-N_i and DO_i are the monitored pollution concentrations in different segments and BOD_0, COD_0, NH_3-N_0 and DO_0 are the guidelines set for the maximal amount of permitted pollution content. If $A \geq 2$, the river water begins to be contaminated with organic matter. We have used the following reference values for the calculation of organic pollution index (Class II).

Table 3 DOE water quality index classification

Parameters	Unit	Classes				
		I	II	III	IV	V
Ammoniacal nitrogen	mg/L	<0.1	1 0.1–0.3	0.3–0.9	0.9–2.7	>2.7
Biochemical oxygen demand (BOD_5)	mg/L	<1	1–3	3–6	6–12	>12
Chemical oxygen demand (COD)	mg/L	<10	10–25	25–50	50–100	>100
Dissolved oxygen	mg/L	>7	5–7	3–5	1–3	<1
pH	–	>7	6–7	5–6	<5	>5
Total suspended solids (TSS)	mg/L	<25	25–50	50–150	150–300	>300
Water quality index (WQI)	mg/L	>92.7	76.5–92.7	51.9–76.5	31.0–51.9	<31.0

$BOD_0 \rightarrow 3$ mg/L

$COD_0 \rightarrow 25$ mg/L

$DO_0 \rightarrow 5$ mg/L

$NH_3 - N_0 \rightarrow 0.3$ mg/L

Statistical analysis

The descriptive statistics and two-way ANOVA on the time series data of water quality parameters were performed to identify significant differences between stations and time. PROC MEANS procedure of Statistical Analytical Systems (SAS) 9.3 (SAS 2012) was used to estimate the descriptive statistics, viz. minimum value, maximum value, mean, standard error and coefficient of variation for various water quality parameters. The significant source of variation (station, time) was detected by analysis of variance adopting the two-way ANOVA using the PROC GLM procedure of SAS 9.3 (SAS 2012). The ANOVA was followed by Tukey's HSD test for analyzing the grouping among the factors (station or time) using the 'MEANS' statement in PROC GLM procedure of SAS 9.3 (SAS 2012). Further, the ten water quality parameters were subjected to factor analysis using PROC FACTOR procedure of SAS 9.3 (SAS 2012) to test whether the water quality parameters are effective in discriminating different stations. Factor analysis is a statistical method used to describe variability among observed, correlated variables in terms of a potentially lower number of unobserved variables called factors. For example, it is possible that variations in four observed variables mainly reflect the variations in two unobserved variables. Factor analysis searches for such joint variations in response to unobserved latent variables. The observed variables are modeled as linear combinations of the potential factors, plus "error" terms. The information gained about the interdependencies between observed variables can be used later to reduce the set of variables in a dataset. Computationally, this technique is equivalent to low rank approximation of the matrix of observed variables. In the factor analysis, the water quality parameters which loaded heavily on the first and second factors were identified. The variables loaded on different factors were selected based on Hatcher's scratching procedure (Hatcher 2003). The statistical procedures were carried out using software platforms of STATISTICA (Hill and Lewicki 2007) and SAS 9.3 (SAS 2012).

Land-use land cover classification

An area of 321 sq. km surrounding the sampling site is analyzed for the land-use land cover classification using ArcGIS 10.2 and ERDAS Imagine 2013 to explore the general contribution by anthropogenic activities towards water quality of the study area. Landsat 7 ETM + satellite imagery having 30 meter resolution from USGS earth explorer is downloaded for the year 2010. This image is used to perform geo referencing and a final RGB band true color and false color imagery is prepared using layer stack tool in ERDAS Imagine 2013. Imagery resolution is increased to 15 m by pan merging technique to increase the accuracy of the results. The final image obtained after preprocessing the satellite imagery is used for classification. Supervised classification is carried out using ERDAS Imagine 2013 for land-use land cover assessment of the study area. The image is classified into four major classes, i.e., vegetation, water bodies, barren land and urban settlements. Area of classes is calculated using histogram value of different bands in true color imagery.

Results and discussion

The site SG1 is located at the side channel (adjacent to the residential area) of the river; SG2 is on the main channel and SG3 on the river mouth. Near stagnant water flow condition was observed at SG1 in comparison with other stations during the monitoring period (SI 1). The overall descriptive statistics (Table 5) for the water quality parameters showed that there is high variation in NH_3-N (coefficient of variance (CV)–177.11 %), P (CV—60.67 %), *E. coli* (CV—49.27 %) and TSS (49.12 %). NH_3-N ranged from 0.005 to 9.86 mg/L with a mean value of 1.52 ± 0.32 mg/L. DO ranged from 0.62 to 6.20 mg/L with mean of 2.84 ± 0.15 mg/L and temperature ranged from 25.80 to 31.80 with a mean value of 30.03 ± 0.10 °C. The acidic pH, existing in the system, ranged from 4.13 to 6.23 with a mean value of 5.05 ± 0.06. COD values ranged from 4 to 71 mg/L with a mean value of 32.08 ± 1.99 mg/L, while BOD values ranged from 2 to 8 mg/L with a mean

Table 5 Descriptive statistics for the water quality parameters

Variable	Mean	Min	Max	Coeff of variation (%)
NH_3-N	1.52 ± 0.32	0.005	9.86	177.11
BOD	3.64 ± 0.18	2	8	42.35
COD	32.08 ± 1.99	4	71	52.6
DO	2.84 ± 0.15	0.62	6.2	45.18
E. coli	134.27 ± 7.8	34.64	322.65	49.27
P	0.36 ± 0.03	0.1	1.14	60.67
TSS	61.17 ± 3.54	18	160	49.12
Temp	30.03 ± 0.1	25.8	31.8	2.78
pH	5.05 ± 0.06	4.13	6.23	9.28

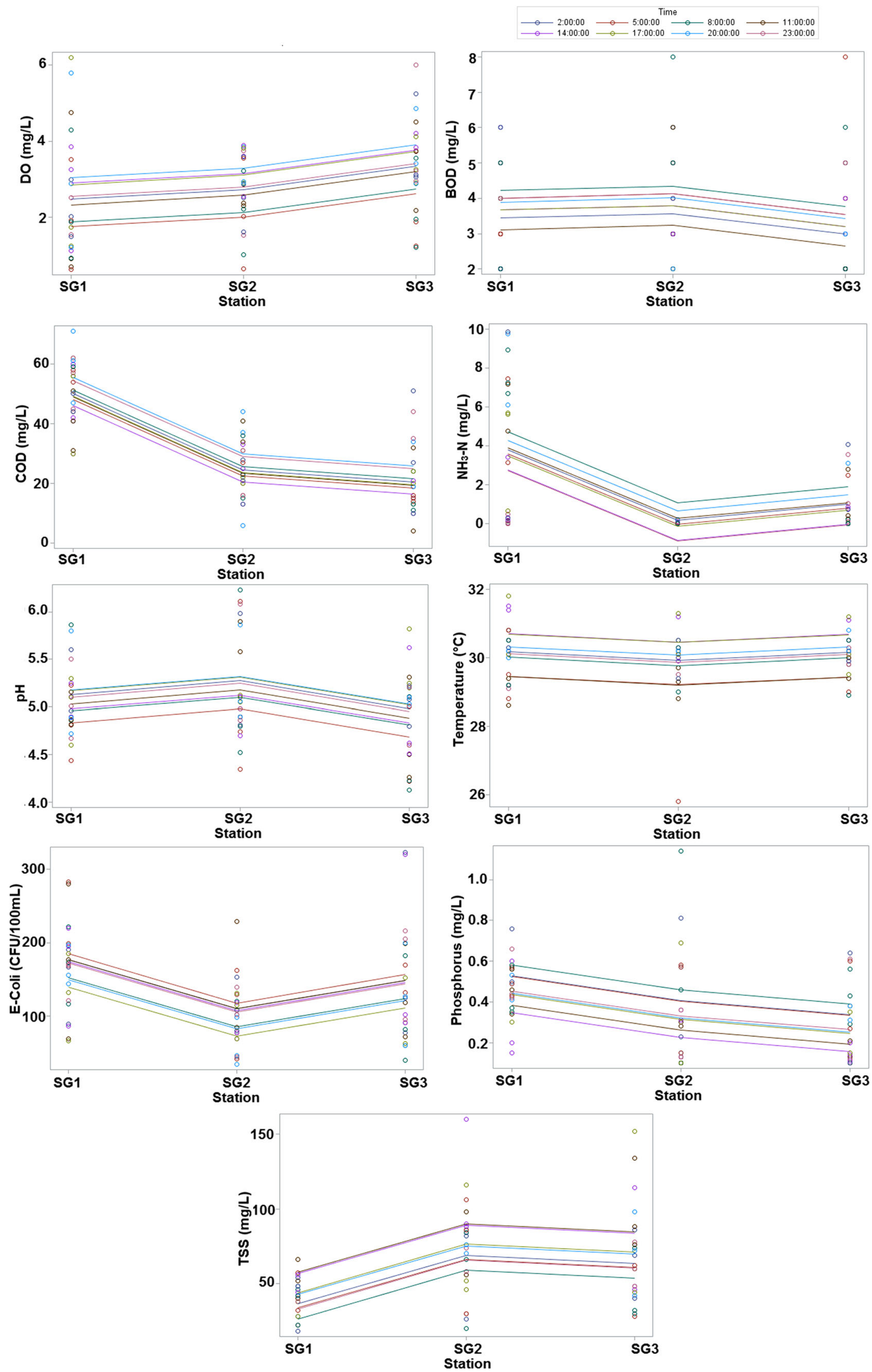

Fig. 2 Interaction plots of time and stations

Table 6 Mean sum of squares from analysis of variance for water quality parameters

	NH_3-N	BOD	COD	DO	*E. coli*	P	TSS	Temperature	pH
Station (2)[a]	86.91**	2.26^{NS}	6175.54**	4.82*	26816.32**	0.22**	7289.04**	0.45^{NS}	0.51^{NS}
Time (7)[a]	4.2^{NS}	1.13^{NS}	91.42^{NS}	1.98^{NS}	2314.15^{NS}	0.05^{NS}	1125.4^{NS}	2.07**	0.13^{NS}
Error (62)[a]	5	2.52	116.55	1.51	3,884.75	0.04	671.55	0.55	0.22
R square	0.4	0.07	0.64	0.2	0.22	0.25	0.35	0.31	0.12

* ($P \leq 0.05$); ** ($P \leq 0.01$). *NS* non significant

[a] Degrees of freedom in parentheses

Table 7 Mean value classifications from Tukey's Studentized Range (HSD) Test

	NH_3-N	BOD	COD	DO	*E. coli*	P	TSS	Temperature	pH
SG1	3.66^{a}	3.75^{a}	50.46^{a}	2.47^{b}	165.86^{a}	0.46^{a}	41.29^{b}	30.11^{a}	5.05^{a}
SG2	0.04^{b}	3.88^{a}	24.92^{b}	2.72^{ab}	99.26^{b}	0.34^{ab}	73.83^{a}	29.87^{a}	5.19^{a}
SG3	0.85^{b}	3.3^{a}	20.88^{b}	3.34^{a}	137.68^{ab}	0.27^{b}	68.38^{a}	30.09^{a}	4.90^{a}

Means with the same letter are not significantly different

Table 8 Factor analysis of the data

Rotated factor pattern				
		Factor 1	Factor 2	Factor 3
Flow		0.46757	0.51151	0.06980
pH		0.10362	0.20495	0.35686
Temp		−0.02756	−0.14756	0.98867
E. coli		0.54637	0.13466	0.32721
BOD		−0.15676	−0.40814	−0.20186
NH_3-N		0.68682	0.01245	0.00922
TSS		−0.41986	0.58361	0.17438
COD		0.60564	−0.34967	0.03079
DO		0.01152	0.44724	0.43950
P		0.10006	−0.62242	0.06879
Eigen value		Difference	Proportion	Cumulative
1	3.70031028	1.50303926	0.6105	0.6105
2	2.19727102	1.37272101	0.3625	0.9730

value of 3.64 ± 0.18 mg/L. P ranged from 0.10 to 1.14 mg/L with a mean value of 0.36 ± 0.03 mg/L, while the TSS ranged from 18 to 160 mg/L with a mean value of 61.17 ± 3.54 mg/L.

Temperature values at all stations have shown a decreasing trend and acidic pH prevailed throughout the observation period. At SG2 and SG3, DO followed the decreasing trend, similar to temperature, and at SG1 low DO is observed as the flow is stagnant most of the time. High BOD and COD were observed at SG1 and SG2 in comparison with the station at the river mouth, SG3. The lower COD and BOD values at SG3 may be probably due to the fast pollutant flushing towards the sea. Similarly, Low TSS values observed at SG1 may be due to the stagnant nature of the side channel in comparison with the main channel. Almost similar trends of high phosphorous at all the stations indicated the anthropogenic addition from an adjacent residential area. High NH_3-N and *E. coli* were observed at SG1 compared to other stations.

Interaction plots between time and stations were generated for different water quality parameters. The time wise distribution of water quality parameters was not significantly different except for temperature. On the other hand, station wise difference was observed for NH_3-N, COD, DO, *E. coli*, Phosphorous and TSS. In addition, the temperature and pH did not show significant difference between the stations. The results are clearly presented in the interaction plots (Fig. 2). Two-way ANOVA (Table 6) showed that there is significant difference between the stations for NH_3-N, COD, DO, *E. coli*, P and TSS. However, there was no significant difference between the stations for BOD, temperature and pH. Time wise significant difference was observed only in case of temperature. The Tukey's HSD test results and classifications for the different water quality parameters based on stations are shown in Table 7. SG1 is found to have higher values in comparison with SG2 and SG3 for NH_3-N, COD, *E. coli* and P, while SG1 has lower values in the case of DO and TSS and it gives an impression that the pollution load would be more in SG1 in comparison with SG2 and SG3. However, there was no significant difference between stations for BOD, temperature and pH.

The factor analysis (Table 8) revealed that the variables with high loadings on the first two factors were found useful in distinguishing the stations. The first two factors (Factor 1–61.05 % and Factor 2–36.25 %) together explained about 97.3 % of the variation in the data. The plot (Fig. 3) between first and second factor scores indicated that these factors were efficient in discriminating the stations SG1, SG2 and SG3. On the basis of the first and

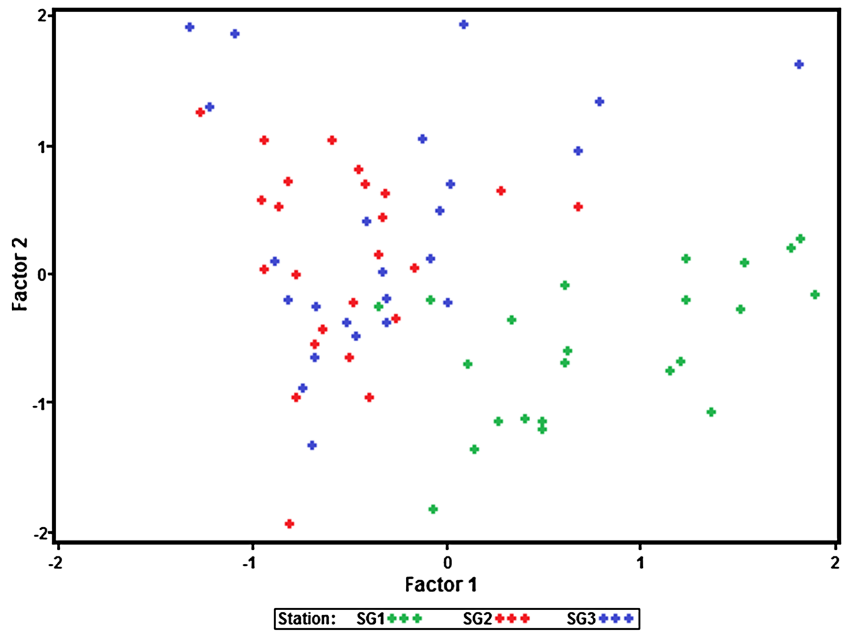

Fig. 3 The scatter plot of the first and second factor scores obtained from the factor analysis of water quality parameters across the sampling locations

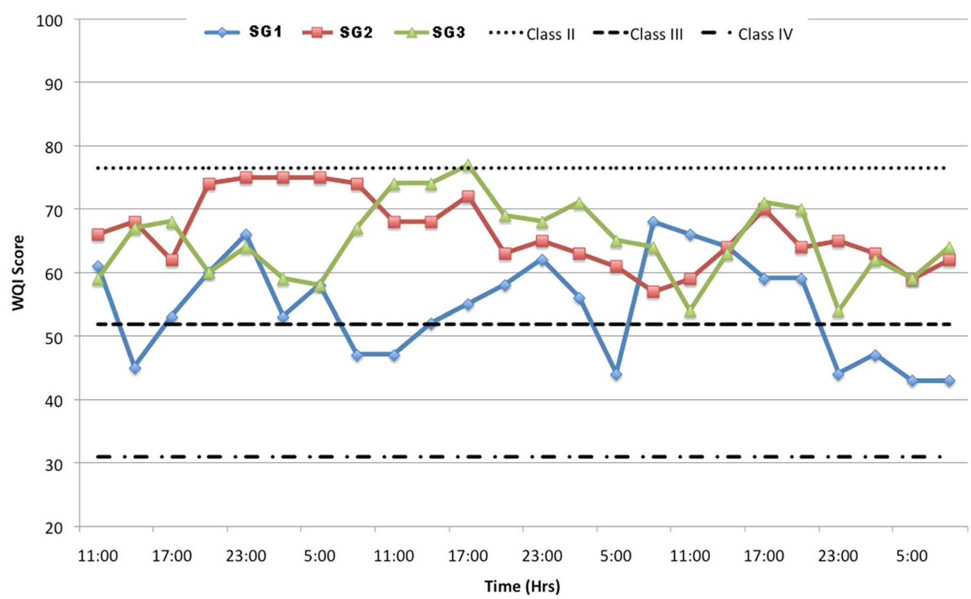

Fig. 4 Water quality index (WQI) score for Sg. Malim/Sg. Sri Melaka

second factors, SG1 is found to be separated from SG2 and SG3. The variables loaded on the first factor were *E. coli*, NH_3-N and COD with positive loadings. The second factor was loaded with TSS (positive loading) and P (negative loading). SG1 was separated from SG2 and SG3 on the basis of higher values of *E .coli*, NH_3-N and COD in SG1. Similarly, SG2 and SG3 were separated from SG1 on the basis of higher values of TSS (Since P negatively loaded on the second factor).

Looking at the water quality trend from a macro perspective, the WQI scores (Fig. 4) indicated that SG1 is the most polluted water body breaching the Class IV threshold during the monitoring period, followed by SG3 and SG2. BOD, COD and TSS at SG1, however, were between Class II and Class III of the NWQS. On the other hand, NH_3-N was relatively high between Classes IV and V of the NWQS, which ultimately contributed to the WQI, breaching Class IV threshold. This was hardly surprising, considering that most of the in-stream flow is augmented, which propels biodegradation producing NH_3-N. Flow retention also caused the in-stream DO levels to be between 1 and 2 mg/L (Class IV), which may be due to the lack of natural re-aeration (Haider et al. 2013). Flow retention inhibits pollutant washout, resulting in particulates settling on the underlying benthos, at the same time prolonging the presence of organic and inorganic constituents within the water body. The sedimentary oxidation further depletes DO levels in the water column. Although the water quality condition at SG1 can already be considered as polluted, further volumetric addition from additional discharge, for example from storm water, would likely result in severe pollution. In addition, the continuous and large volumetric discharge would have nowhere to go as the manual floodgate in the channel is closed most of the time. This presents the possibility of odor problems due to anaerobic decomposition, which may be a nuisance to the residents.

SG2 is located on the upstream segment of the river and water quality conditions here can be considered to be moderate, with a consistent Class III WQI rating. The relatively low pollutant levels indicated that the upstream land-use activities appear to exert a marginal impact on the in-stream water quality. The water quality status at SG2 (main stem) is observed to be between Classes II and III of the NWQS for majority of the constituents measured. DO levels, however, are still relatively low as reflected in the low in situ DO readings. SG3 is located near the mouth and reflects the impact of the side channel towards the water quality (SG1), post-confluence. Despite this fact, there is a very clear concentration increment post-confluence with the channel. The overall WQI score depletes to a lower value most of the time while still being within the Class III denotation. Some increment in organic levels (BOD and COD) was observable, though the most significant increase in SG2 was for NH_3-N, P and *E. coli*.

The OPI (Fig. 5) can be relied on as an immediate measure of the overall health of a river ecosystem. The mean OPI at SG3 (4.11) lies between that of SG1 (14.99) and SG2 (2.57). SG3 is most susceptible to flushing by sea water and is normally expected to be least polluted. But,

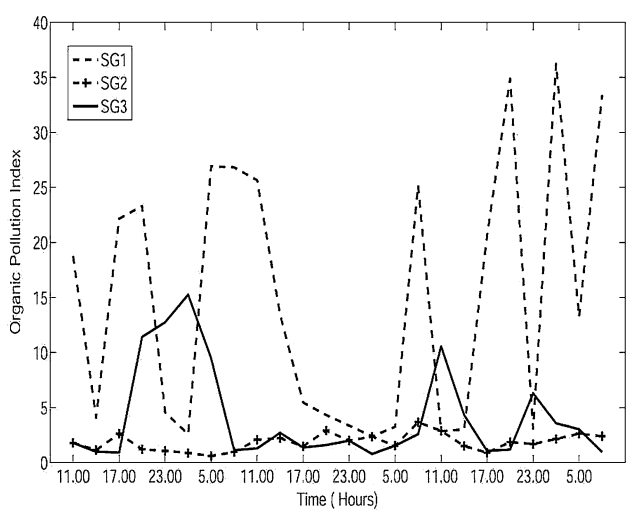

Fig. 5 Organic pollution Index at three stations

SG3 also receives the pollutant load from the side channel. SG2 is located upstream so that the effect of pollutant from the side channel is not seen at SG2. Finally, the land-use land cover classification of the study area shows that the region near the sampling sites is dominated by urban settlements compared to other classes. The image is classified into four major classes, i.e., vegetation, water bodies, barren land and urban regions (Fig. 6). Urban regions (Table 9) constitute about 106.70 sq km in the total studied area of 321 sq km, followed by vegetation (112.27 sq km), barren land (87.60 sq km) and water bodies (14.43 sq km). The urban area comprises 33.23 % of the total studied area. This is a major sign of anthropogenic activities which can be responsible for water quality deterioration in the river. Once the urbanization process commences, it will expand into nearby areas also. Urbanizing streams pose particular

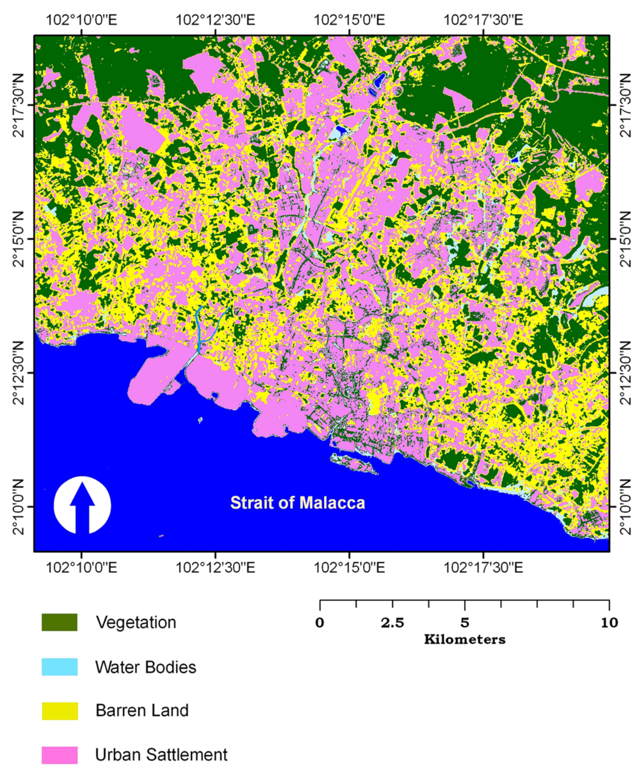

Fig. 6 Land-use land cover classification carried out using ERDAS Imagine 2013

Table 9 Classifications by land-use land cover assessment of the study area

Classes	Area in sq km	Total area (%)
Vegetation	112.27	34.97
Water bodies	14.43	4.50
Barren land	87.60	27.30
Urban settlements	106.70	33.23

challenges for management given an inherent changing nature (Chin 2006). If unchecked, the present pollution problem will evolve into a serious environmental problem in the near future and will affect the delicate environmental balances and interactions.

Conclusion

The short-term water quality trend is analyzed for an urban river. The low DO levels will lead to the mortality of aquatic flora/fauna, the decomposition of which further decreases the availability of already depleted DO levels. This can eventually drive the riverine ecosystem from oxic to hypoxic and then to anoxic conditions. Understanding the water quality trend is a prerequisite in sustainable management of the river water and adjacent ecosystem. This also governs the self-purification capacity of the river and will aid in following the national water quality standards and keep the ambient conditions of the river. The present study is also a base for future water quality modeling studies for predicting long-term changes in the era of climate change and increased anthropogenic pressures.

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References

Abbasi T, Abbasi SA (2012) Water quality indices. Elsevier, Oxford

Allan JD (2004) Landscapes and riverscapes: the influence of land use on stream ecosystems. Annu Rev Ecol Evol Syst 35:257–284

Asry Z, Samsudin AR, Yaacob WZ, Yaakub J (2012) Groundwater investigation using electrical resistivity imaging technique at Sg. Udang, Malaka, Malaysia. Bull Geol Survey Malays 58:55–58

Belayneh M, Bhallamudi S (2012) Optimization model for management of water quality in a tidal river using upstream releases. J Water Resour Prot 4:149–162

Ben Belgacem F (2012) Uniqueness for an ill-posed reaction-dispersion model, application to organic pollution in stream-waters. Inverse Probl Imaging 6:163–181

Buffers RF (2000) Effects on water quality. Virginia Cooperative Extension Publication

Chen C, Tang S, Pan Z, Zhan H, Larson M, Jönsson L (2007) Remotely sensed assessment of water quality levels in the Pearl River Estuary, China. Mar Pollut Bull 54:1267–1272

Chin A (2006) Urban transformation of river landscapes in a global context. Geomorphology 79:460–487

Dede OT, Telci IT, Aral MM (2013) The use of water quality index models for the evaluation of surface water quality: a case study for Kirmir Basin, Ankara, Turkey. Water Qual Expo Health 5:41–56

DOE (Department of Environment Malaysia) (1985) Development of water quality criteria and standards for malaysia. Department of Environment, Malaysia

DOE (Department of Environment Malaysia) (2007) Malaysia environmental quality report 2006. In: Chapter 3: river water quality. Sasyaz Holdings Sdn Bhd. 24 pp

Garnier J, Brion N, Callens J, Passy P, Deligne C, Billen G, Servais P, Billen C (2013) Modeling historical changes in nutrient delivery and water quality of the Zenne River (1790s–2010): the role of land use, waterscape and urban wastewater management. J Mar Syst 128:62–76

Gazzaz NM, Yusoff MK, Aris AZ, Juahir H, Ramli MF (2012) Artificial neural network modeling of the water quality index for Kinta River (Malaysia) using water quality variables as predictors. Mar Pollut Bull 64:2409–2420

Haider H, Ali W, Haydar S (2013) Evaluation of various relationships of reaeration rate coefficient for modeling dissolved oxygen in a river with extreme flow variations in Pakistan. Hydrol Process 27:3949–3963

Hatcher L (2003) A step by step approach to using SAS for factor analysis and structural equation modelling. SAS Institute Inc, Cary

Hill T, Lewicki P (2007) STATISTICS: methods and applications. StatSoft, Tulsa

Krom MD (1986) An evaluation of the concept of assimilative capacity as applied to marine waters. Ambio 15:208–214

Lambin EF, Geist HJ, Lepers E (2003) Dynamics of land-use and land-cover change in tropical regions. Annu Rev Environ Resour 28:205–241

Lumb A, Sharma TC, Bibeault JF (2011) A review of genesis and evolution of water quality index (WQI) and some future directions. Water Qual Expo Health 3:11–24

Meyers WB, Turner BL II (1992) Human population growth and global land use/cover change. Annu Rev Ecol Syst 23:39–61

Meyfroidt P, Lambin EF, Erb KH, Hertel TW (2013) Globalization of land use: distant drivers of land change and geographic displacement of land use. Curr Opin Environ Sustain 5:438–444

Saffran K, Cash K, Hallard K, Neary B, Wright R (2001) CCME water quality index 1.0 user's manual. Canadian water quality guidelines for the protection of aquatic life, Canadian environmental quality guidelines. Canadian Council of Ministers of the Environment

SAS Institute SAS/STAT (2012) User's guide, version 9.2, 4th edn, vol 1. SAS Institute, Cary

Shirodkar PV, Pradhan UK, Fernandes D, Haldankar SR, Rao GS (2010) Influence of anthropogenic activities on the existing environmental conditions of Kandla Creek (Gulf of Kutch). Curr Sci India 98:815–828

Tett P, Portilla E, Gillibrand PA, Inall M (2011) Carrying capacity and assimilative capacities: the ACExR-LESV model for sea loch aquaculture. Aquac Res 42:51–67

VishnuRadhan R, Vethamony P, Zainudin Z, Kumar VK (2014) Waste assimilative capacity of coastal waters along Mumbai megacity using MIKE21 and WASP simulation models. Clean 42:295–305

VishnuRadhan R, Sagayadoss J, Seelan E, Vethamony P, Shirodkar P, Zainudin Z, Shirodkar S (2015) Southwest monsoon influences the water quality and waste assimilative capacity in the Mandovi estuary (Goa state, India). Chem Eco 31:217–234

Wei GL, Yang ZF, Cui BS, Chen H, Bai JH, Dong SK (2009) Impact of dam construction on water quality and water self-purification capacity of the Lancang River, China. Water Resour Man 23:1763–1780

Whitehead PG, Crossman J, Balana BB, Futter MN, Comber S, Jin L, Skuras D, Wade AJ, Bowes MJ, Read DS (2013) A cost-effectiveness analysis of water security and water quality: impacts of climate and land-use change on the River Thames system. Philos Trans R Soc A 371:20120413

Wu KY, Ye XY, Qi ZF, Zhang H (2013) Impacts of land use/land cover change and socioeconomic development on regional ecosystem services: the case of fast-growing Hangzhou metropolitan area, China. Cities 31:276–284

Zainudin Z (2010) Benchmarking river water quality in Malaysia. Jurutera, pp 12–15

Zainudin Z, Ansari AH, Baharudin H (2013) Riparian zone management and rehabilitation in Malaysia through restorative justice. Adv Environ Biol 7:3264–3270